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Effect of a redesigned two-wheeled container for refuse collecting on mechanical loading of low back and shoulders

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The objective of this study was to compare the mechanical and perceived workload when working with a redesigned two-wheeled container and working with a standard two-wheeled container for refuse collecting. The three changes in the design of the container were a displacement of the position of the centre of mass in the direction of the axis of the wheels, a slight increase in the height of the handle and a slight increase in the horizontal distance between the handle and the wheel-axis, and an increase in the diameter of the wheels. The volume of the container remained 0.240 m^3. Nine refuse collectors performed some of their most frequent daily activities with both types of containers in the laboratory. Kinematics and exerted hand forces were assessed as input for detailed 3D biomechanical models of the low back and shoulder to estimate net moments at the low back and shoulders, compressive forces at the low back and contact forces at the glenohumeral joint. Also, the refuse collectors rated the ease of handling the two-wheeled containers on a five point scale. The use of the redesigned container resulted in a decrease of the exerted hand forces of 27%, decreases in the net moments at the low back and shoulders of 8% and 20%, respectively, and a decrease of 32% of the contact force at the glenohumeral joint when compared to the standard container. However, pulling an empty redesigned container on to the pavement resulted in an increase of the shoulder moment of more than 100%. No differences between container types were found for the compressive forces at the low back. Pushing and pulling with the redesigned container was rated as easier than pushing and pulling with the standard container. No differences in subjective ratings were found for the tasks of turning the container or pulling an

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empty container onto the pavement. It is concluded that, provided that empty containers are placed back onto the pavement as infrequently as possible, the introduction of the redesigned container could result in a reduction of the low back and shoulder load for refuse collectors.

1. Introduction

Working as a refuse collector is a physically demanding job. Several studies showed that the physical workload of refuse collectors can be classified as high (Kemper *et al*. 1990, Frings-Dresen *et al*. 1995a, Schibye and Christensen 1997). In most parts of The Netherlands, refuse bags have been replaced by two-wheeled containers to reduce the workload and the risk of musculoskeletal complaints (Frings-Dresen *et al*. 1995b). The replacement of lifting by pushing and pulling resulted in a marked reduction of compressive forces at the low back (De Looze *et al*. 1995, Schibye *et al*. 2001). However, pushing and pulling tasks are also suggested to be a risk factor for developing pain or stiffness in the neck and shoulder region (Van der Beek *et al*. 1993, Hughes *et al*. 1997, Hoozemans *et al*. 1998). A further reduction of the mechanical load on low back and shoulders might be achieved by ergonomically optimizing the design of the two-wheeled container.

A previously performed study suggested that two aspects of the two-wheeled container are of importance: the position of the centre of mass (COM) and the position of the handle (Kingma *et al*. 2003). Kingma *et al*. (2003) studied the effect of the COM position and the handle position for steady, symmetrical, two-handed pushing and pulling on forces exerted and on joint loading. A displacement of the COM towards the axis of the wheels resulted in a slight reduction in joint loading as well as in an increased stability of the container. This increased stability probably reduces the risk of unexpected disturbances in the mechanical equilibrium due to irregular surfaces, thereby requiring smaller and less frequent force adaptations. Furthermore, any handling of a two-wheeled container starts with tilting. The displacement of the COM towards the wheel axis roughly halved the required horizontal tilting force. The effect of the handle position on exerted forces and joint loading was less pronounced. An increase in the height of the handle of about 0.1 m and an increase in the horizontal distance between the handle and the wheel-axis of about 0.1 m resulted in a small reduction of the vertical force and of the loading of the elbow and shoulder, without adverse effects on low back loading. A more than 0.1 m increase in handle position caused refuse collectors with a relatively short body height to tilt the container quite far. This relatively large tilt angle resulted in an increased joint loading.

Before implementing such an expensive work improvement, it is imperative to establish its effect on the workload of the refuse collectors. Therefore, an efficacy study was performed with both standard and redesigned two-wheeled containers in which the most frequent daily activities were studied in terms of mechanical workload of the low back and shoulder. Because most activities with a two-wheeled container are not performed symmetrically (Madeleine *et al*. 2000), detailed 3D biomechanical models were used to evaluate the effects. In order to gain more insight in the ease of use, the refuse collectors also rated the handling of both types of containers. In summary, the aim of this study was to compare the mechanical and perceived workload when working with a redesigned two-wheeled container and when working with a standard two-wheeled container for refuse collecting.

2. Methods

2.1. *Participants*

Nine healthy male refuse collectors participated in the experiment. They were employed by different refuse companies in The Netherlands and had had at least 1 year of experience with collecting refuse using two-wheeled containers. Body height is likely to have a large influence on posture and joint loading while working with two-wheeled containers. Therefore, a group of refuse collectors with a large range in body height was selected. The mean (standard deviation) of age was 33 (6) years, of body height 178 (11) cm, and of body weight 82 (19) kg. All refuse collectors gave informed consent prior to the experiment and reported no musculoskeletal problems at that moment.

2.2. *Design of two-wheeled containers*

Two two-wheeled containers were used in the experiment: (1) a standard two-wheeled container (Otto, 0.240 m^3) and (2) a redesigned two-wheeled container with the same volume. The redesign was based on the results of the aforementioned study on the effect of handle position and COM position on mechanical loading (Kingma *et al.* 2003). The handle was displaced 0.1 m rearwards in the horizontal direction closer to the refuse collector, and 0.1 m upwards in the vertical direction (as shown in figure 1). The diameter of the wheels was increased from 0.2 to 0.3 m. Although the laws of rolling resistance are not yet definitely established, a widely accepted relationship is that the horizontal push force of a cart is equal to the coefficient of friction times the total weight of the cart divided by the wheel radius (Al-Eisawi *et al.* 1999). Therefore, an increase in diameter of the wheels of about 50% might be expected to result in a reduction of the horizontal pushing force of about 30%. However, in this study, not only the wheel size was altered but also the width of the wheel was increased and another type material for the wheels was used. It was expected that both changes would result in a reduction of the horizontal force.

Changes in the width and depth of the container and in the position of wheel axis were performed in such a way that, assuming a homogeneous filling, it resulted in a displacement of the COM about halfway towards the axis of the wheels (figure 1). By widening the container, the wheel-axis was lengthened from 0.55 m (standard two-wheeled container) to 0.69 m (redesigned two-wheeled container). The COM positions in the standard and redesigned containers were created by simulating the load in the container using blocks of foam and lead. On average, a loaded two-wheeled container weighs about 40 kg and an extremely heavy two-wheeled container more than 60 kg. In the Netherlands, two types of refuse are collected using two-wheeled containers so-called green ('organic fraction') and grey ('non-organic fraction') refuse. Therefore, the actual position of the COM was calculated for three different container-filling conditions (figure 1) with masses (including weight of the container) of about 40 kg (mean weight 'organic fraction'), 45 kg (mean weight 'non-organic fraction') and 74 kg ('very heavy container'). Information on the density of refuse was received from the National Institute of Public Health and Environment.

2.3. *Experimental arrangement*

A brick-paved road and a pavement of tiles were built in the laboratory. The road was 6 m long and 2.5 m wide. The area of the pavement was 1.5 m × 1.5 m.

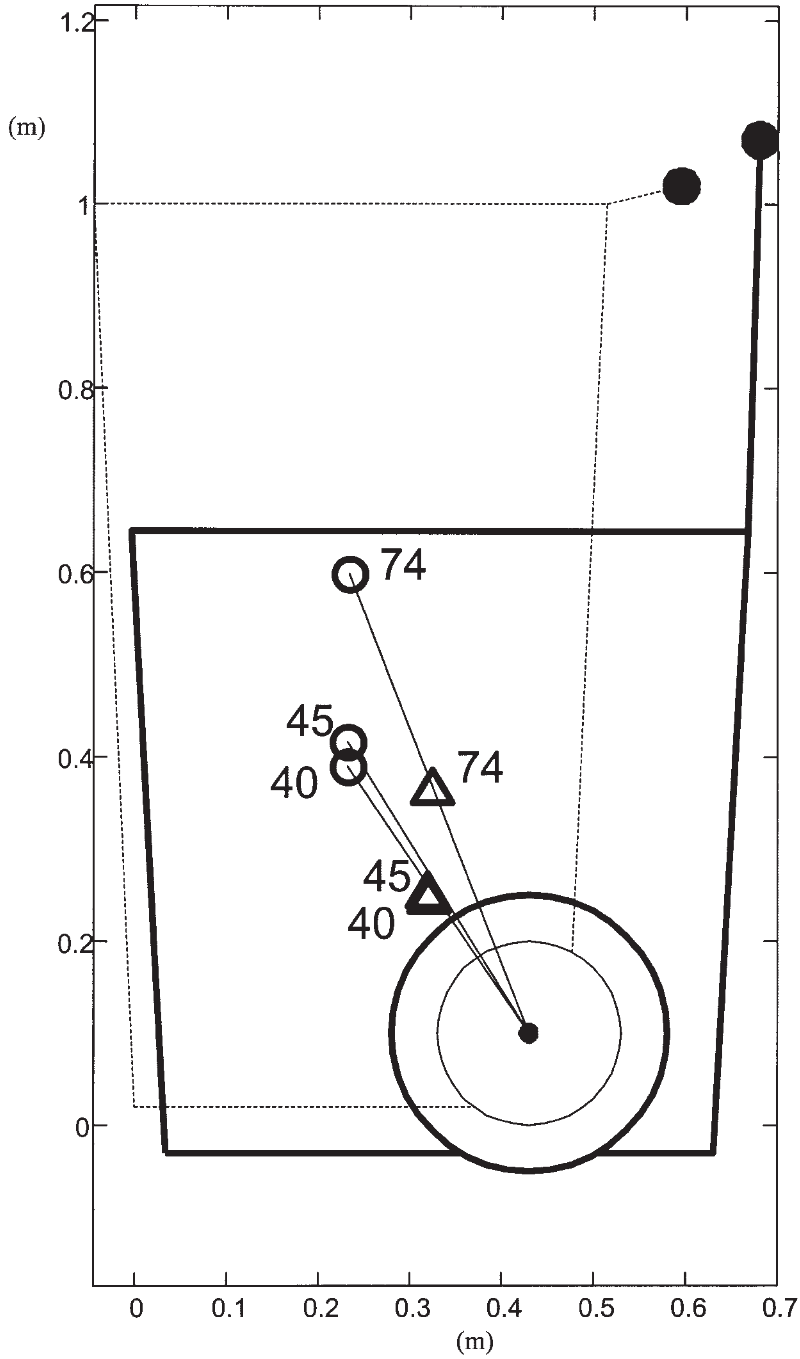

Figure 1. A schematic presentation of the dimensions (height: vertical axis; depth: horizontal axis, and width: not visible in this 2D representation) of the standard (- - -) and redesigned (—) two-wheeled container. The positions of the three centres of mass (COM) are indicated (circles: standard container; triangles: redesigned container) in three loading conditions (with masses of 40, 45 and 74 kg including the weight of the container).

The pavement was about 0.13 m higher than the surface of the road. The most frequent daily activities with a two-wheeled container were performed: (1) tilting the two-wheeled container and pulling it with one hand (with the container behind the back), (2) tilting the two-wheeled container and pushing it with two hands, (3) turning the two-wheeled container around, in order to position the container correctly when one handed pulling behind the back was followed by two handed pushing in front of the body, and (4) pulling the empty two-wheeled container up onto the pavement. For the last two activities, the refuse collectors were free to do it with one or two hands. The only restriction was that they had to do it with the same number of hands with the other type of two-wheeled container. The first three activities were performed with the three different container fillings. In accordance with the real working situation, the last activity was only performed with an empty two-wheeled container. The empty standard two-wheeled container weighed 20 kg and the empty redesigned container 21.2 kg. Four refuse collectors started with the standard two-wheeled container and the other five started with the redesigned two-wheeled container. The order of the three container fillings was selected at random. With each filling, the activities 1 to 3 were performed in that order. When these three activities had been performed with all three fillings, activity 4 was performed with the empty container. Then the activities were performed with the other two-wheeled container. Again, the same procedure was followed. Before each experimental test condition (trial), the refuse collectors practised with the two-wheeled container.

2.4. *Measurement of exerted hand forces and kinematics*

Both handles of the container were replaced with handles separately attached to a 3D force transducer (SRMC3A series, Advanced Mechanical Technology, Inc., USA). The handles were placed in the correct position by removing the lid of the containers and by adding aluminium bars to the construction. To ensure that the weights of the force transducers and the aluminium bars did not influence the mechanical properties of the container, such as the location of the COM, blocks of foam and lead were placed in the container. In addition, markers were attached to the left and right side of the container at the centre of the handles and above the axis of the wheels. The 3D marker positions were recorded using an opto-electronic system, using an array of two cameras on both sides of the body (Optotrak, Northern Digital Inc., Canada). The exerted forces and marker positions were sampled at 50 Hz. The markers on the container were used to calculate the tilt angle of the container during each trial. Using this angle, the forces at the handles were transformed from local to global three dimensional co-ordinates. The exerted forces were calculated as the sum of the forces exerted at the left and right handles.

LED markers were attached to the left and right side of the subject's body at the L5-S1 joint according to the procedures recommended by De Looze *et al.* (1992). A cuff consisting of eight markers was attached around the wrist of the right arm. Two markers were attached at the acromioclavicular joint of the right shoulder. One marker was placed at the left shoulder. A cuff of five markers was placed at the right elbow. One marker was placed at the left elbow. A cuff of eight markers was attached at the right side of the thorax.

2.5. *Biomechanical model of the low back*

Kinematics and anthropometric data were used as input for an upper body quasi-dynamic 3D linked segment model (Kingma *et al*. 1996). The linked segment model consisted of five segments: left and right forearms plus hands, left and right upper arms, and trunk plus head. Net moments at the L5-S1 level were calculated using standard linked segment mechanics.

During the experimental pushing and pulling activities surface-EMG recordings were made of eight bilateral muscle pairs of the trunk, following the procedures of Van Dieën and Kingma (1999) using bipolar disposable Ag-AgCl electrodes. The eight muscles were m. multifidus, m. longissimus thoracis, m. iliocostalis lumborum, m. rectus abdominis, m. obliquus externus abdominis (anterior), m. obliquus externus abdominis (lateral), m. obliquus internus abdominis (anterior) and m. obliquus internus abdominis (lateral). Signals were first amplified 20 times, and then band-pass pre-filtered (10–400 Hz) and A-D converted (22 bits at 1600 Hz). All signals were high-pass filtered at 30 Hz to reduce cardio-electric interference (Redfern *et al*. 1993), and subsequently low-pass filtered (Butterworth) at 2.5 Hz after full-wave rectification. Filtered data were normalized to the maximum value found in maximum voluntary contraction tests derived from McGill (1991).

An EMG driven distribution model was used to estimate compressive forces at the L5-S1 level. The model has for the most part been described previously (Van Dieën 1997, Van Dieën and Kingma 1999). Muscle forces were estimated as the product of maximum muscle stress, normalized EMG amplitude, and correction factors for instantaneous muscle length and contraction velocity plus the passive force developed by the muscle's connective tissue. Maximum muscle stress was iteratively adjusted to obtain maximum agreement between the time series of muscle moments and net external moments (McGill and Norman 1986). The anthropometry of the model was scaled to the anthropometry of the participants. By doing this, individual characteristics of the refuse collector, such as length and weight of the trunk, were taken into account. Compressive forces were determined by the sum of the forces of the muscle slips as defined by the model, the gravitational forces resulting from the mass of the upper body, and the reaction forces at the hands.

2.6. *Biomechanical model of the shoulder*

The mechanical loading of the shoulder was estimated using a dynamic 3D shoulder-elbow model (Van der Helm 1991, Van der Helm and Veeger 1999). The model is based on finite element theory (Van der Helm 1994) and has been validated in several studies (Van der Helm 1991, Happee and Van der Helm 1995, De Groot 1998). Due to the complexity of assessing valid kinematic data for the shoulder model, only the right arm was analysed. Standardized postures of the participants were assessed prior to the experiments to record the position of LED markers on bony landmarks in relation to LED marker positions on the trunk and on the right lower and upper arm (Van der Helm and Veeger 1996). During the experiments, these LED marker positions and the marker on the acromioclavicular joint were used to predict the position of the scapula and the clavicle. The glenohumeral joint rotation centre was predicted on the basis of the orientation of the scapula (Meskers *et al*. 1998). Unlike the biomechanical model of the low back, the anthropometry of the participants was used to scale the anthropometry of the model (Veeger *et al*. 1991, Veeger *et al*. 1997). The shoulder-elbow model is a model based on one specimen. Input to this model is a set of joint angles (trunk, arm, forearm and wrist) with a limited set of shoulder landmark positions that are used by the model to estimate the orientation of the scapula. Scaling of the anthropometry of the participants to the model only involved the position of these landmarks to correctly estimate this orientation. Angles do not need to be scaled. Scaling the model to the anthropometry of the subjects is a rather awkward procedure, since this would involve scaling all definitions of anatomical structures and geometric elements. This would inevitably lead to calculation problems and, more importantly, would involve decisions on a correct scaling method. To date no valid scaling method is available. The kinematics of the right arm and the forces exerted at the right hand were used to calculate the net moment and force components around three axes through the right glenohumeral joint.

2.7. *Subjective rating*

After each trial, the refuse collectors were asked to rate whether handling the standard and redesigned container was more or less easy than handling a 'normal two-wheeled container'. A normal two-wheeled container referred to the container which the refuse collector used in daily practice. The designs of all 0.240 m^3 containers are similar, but there are small differences between different brands. A five point scale was used, ranging from 1 ('easier') to 5 ('less easy'). When the handling was felt to be comparable to handling a normal two-wheeled container, this was rated as 3 on the scale.

2.8. *Data analyses*

The force exerted and net moment components were used to calculate the resultant forces exerted and resultant net moments at the low back and shoulder joint. The peak exerted force, peak net moment at the low back and shoulder, and peak compressive force at the low back were determined for each trial. Peak value was defined as the 90th percentile of the distribution of values found during the whole trial. This definition was used to reduce the risk of analysing measurement errors. Due to a frequent loss of some LED markers, it appeared not to be possible to estimate contact forces at the glenohumeral joint for all trials and also not for the complete trial. Therefore, the peak contact force at the glenohumeral joint was only determined for the tilting phase in pulling and pushing. Sustained values were determined for the resultant exerted force, the resultant net moment at the low back and shoulder and the compressive forces at the low back. Because the containers are only pushed and pulled over a relatively small distance in daily practice, there is no real 'steady state' pushing or pulling. Therefore, the sustained value while pushing or pulling the container was calculated at a relatively high but more or less constant speed. The sustained value was defined as the average value in a 1.5 s window during which the velocity of the container was higher than the mean velocity of the container, while at the same time the period contained the lowest mean acceleration of all 1.5 s periods that fit within the time that the velocity was higher than the mean velocity. A window of 1.5 s was chosen, because at least one step is taken with the left and right foot. The sustained values were calculated for pulling with one hand and pushing with two hands. The other two activities were very dynamic and of short duration. Therefore, it was not meaningful to calculate a mean value.

For each of the four activities, the effect of the type of two-wheeled container on all measures of the forces exerted, net moments, and compressive and contact forces were statistically tested using generalized estimating equations (GEE) (Liang and Zeger 1993, Twisk 1997). The analysis considered the measurements within participants as a repeated measurement and accounted for this dependency in the regression analysis. In addition, the effect of the total weight of the two-wheeled container was taken into account. In the GEE analysis the factors of interest were coded according to equation (1).

$$X = C + B1 \cdot \begin{pmatrix} \text{standard two-wheeled container}=0 \\ \text{redesigned two-wheeled container}=1 \end{pmatrix} + \\ B2 \cdot \text{weight (kg)} + B3 \cdot \begin{pmatrix} \text{standard two-wheeled container}=0 \\ \text{redesigned two-wheeled container}=1 \end{pmatrix} \cdot \text{weight (kg)} \tag{1}$$

where B1-B3 are regression coefficients and the constant (C) comprises the hypothetical value of the outcome measure (X) when moving a standard two-wheeled container with a weight of 0 kg. A difference between both two-wheeled containers was marked as significant when regression coefficient B1 or B3 was statistically significant (p-value <0.05).

A difference between the subjective ratings of the two types of two-wheeled containers was tested with a Wilcoxon signed rank test for matched pairs. Again, a significance level of 5% was used. The mean values of the subjective ratings for pushing, pulling, turning and pulling an empty container onto the pavement are indicated in the results.

3. Results

3.1. *Exerted hand forces*

The use of the redesigned two-wheeled container resulted in lower peak and sustained exerted hand forces compared to the standard two-wheeled container for the activities of pulling (peak, p-value $B1 = 0.00$; sustained, p-value $B1 = 0.00$) and pushing (peak, p-value $B1 = 0.00$; sustained, p-value $B1 = 0.00$) and a lower peak value for turning (peak, p-value $B1 = 0.00$) (figure 2). The peak force for pulling an empty two-wheeled container on the pavement did not differ significantly between the two types of containers. It should be noted that three refuse collectors used two hands and two refuse collectors

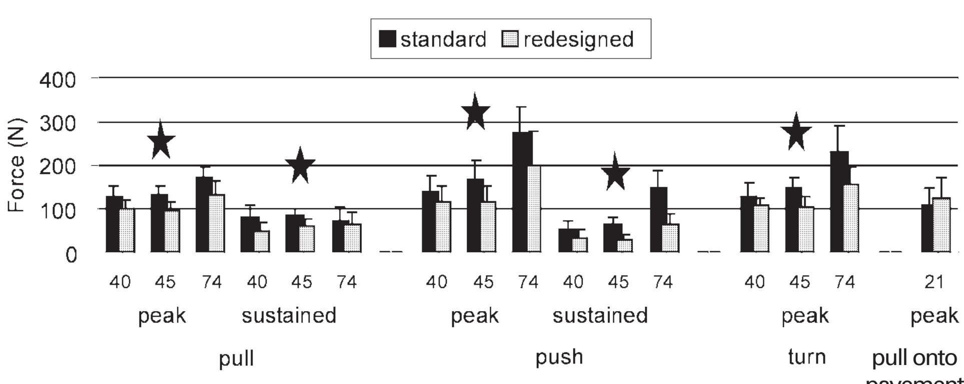

Figure 2. Mean and standard deviation of exerted force (sustained and peak) for pulling, pushing and turning the standard and the redesigned containers with the three different weights (40, 45 and 74 kg) and for pulling the empty containers (21 kg) onto the pavement (★ statistically significant difference).

used one hand for turning the container, independent of the weight of the container. For the other refuse collectors, it depended on the weight of the container.

3.2. *Moments at the low back and the shoulder*

The peak moment at the low back for pushing the redesigned container was lower than for pushing the standard container (p-value B1 = 0.03) (figure 3). The same effect was found for the peak moment at the low back for turning (p-value B1 = 0.02). The peak moments at the low back for pulling a loaded container and for pulling an empty container onto the pavement did not differ between the two types of containers. The sustained moments at the low back during pulling and pushing also did not differ between the two types of containers.

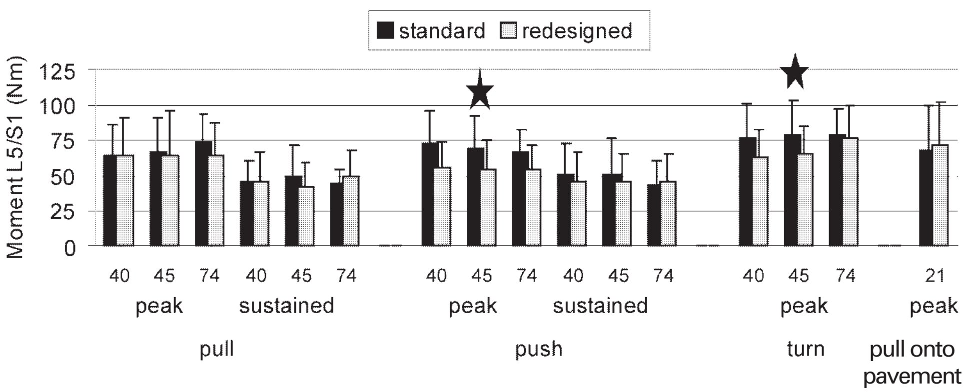

Figure 3. Mean and standard deviation of moment at the low back (L5/S1) (sustained and peak) for pulling, pushing and turning the standard and the redesigned containers with the three different weights (40, 45 and 74 kg) and for pulling the empty containers (21 kg) onto the pavement (★ statistically significant difference).

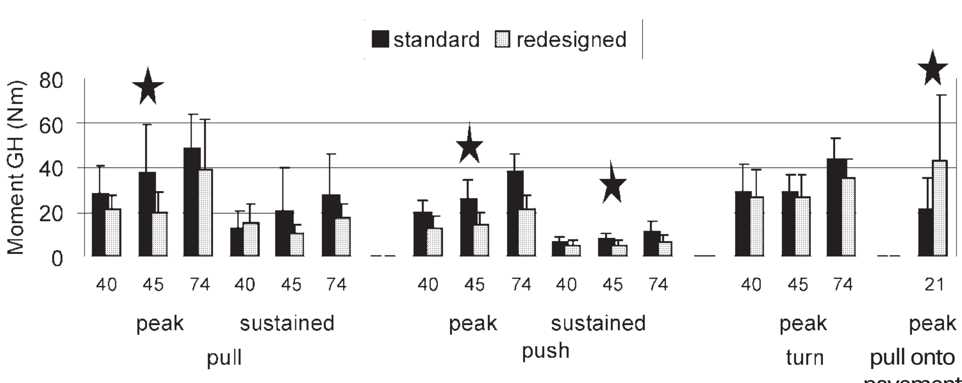

Figure 4. Mean and standard deviation of moment at the glenohumeral joint (GH) (sustained and peak) for pulling, pushing and turning the standard and the redesigned containers with the three different weights (40, 45 and 74 kg) and for pulling the empty containers (21 kg) onto the pavement (★ statistically significant difference).

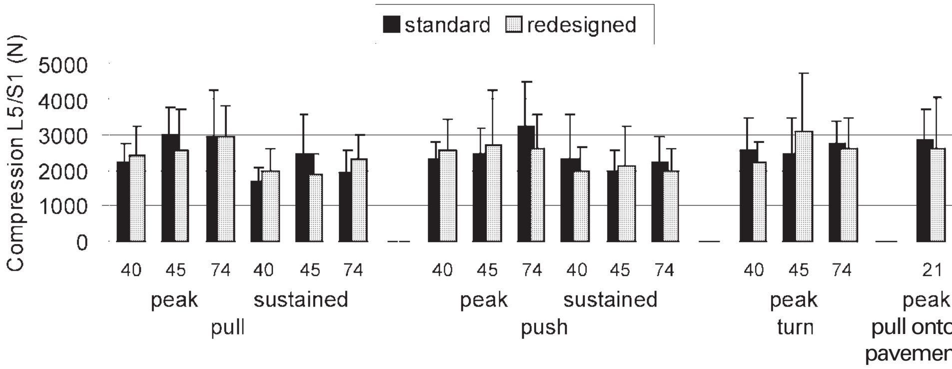

Figure 5. Mean and standard deviation of compression force at the low back (L5/S1) (sustained and peak) for pulling, pushing and turning the standard and the redesigned container with the three different weights (40, 45 and 74 kg) and for pulling the empty (21 kg) standard and the empty redesigned container on the pavement.

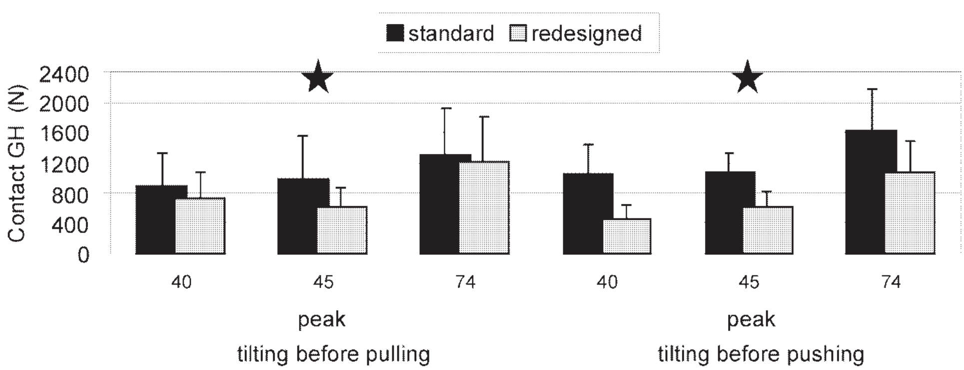

Figure 6. Mean and standard deviation of contact force at the glenohumeral joint (GH) (sustained and peak) for tilting (before pulling and pushing) the standard and the redesigned containers with the three different weights (40, 45 and 74 kg) (★ statistically significant difference).

The use of the redesigned container resulted in lower sustained and peak moments around the shoulder for pushing (sustained, p-value B1 = 0.00; peak, p-value B1 = 0.00) (figure 4). For pulling, a reduction was found for the peak moment only (p-value B1 = 0.01). The peak moment for turning the container did not differ between the two types of containers. Remarkably, the use of the redesigned two-wheeled container resulted in a higher peak moment while pulling an empty container onto the pavement (p-value B1 = 0.04).

3.3. *Compression force at the low back and contact force at the shoulder joint*

The type of two-wheeled container did not affect the compression force at the low back (figure 5). However, the type of container did affect the peak contact force at the shoulder joint (figure 6). The peak contact force was lower for tilting the redesigned container than for tilting the standard container (p-value B1 = 0.00).

3.4. *Subjective ratings*

The participants experienced pushing and pulling the redesigned container as easier than pushing and pulling the standard container (pushing, *p*-value = 0.00; pulling, *p*-value = 0.00) (figure 7). As expected, the subjective ratings of pushing and pulling the standard container did not differ from pushing and pulling a normal container in daily practice. No differences in subjective ratings were found between the two containers for turning and pulling the empty container onto the pavement.

4. Discussion

4.1. *Limitations of the study*

The objective of the present study was to compare the exerted forces, mechanical loading of the low back and shoulders and perceived workload while working with a standard and a redesigned two-wheeled container for refuse collecting. In order to increase the external validity of the study, the most frequent daily activities with a container (with a mean and with a heavy load) were performed in the laboratory. However, due to the setting in the laboratory and the presence of measuring devices on the body of the refuse collectors, absolute values might be higher in daily practice. Because this effect is probably independent of the type of container, it has probably no consequences for the comparison made between the two types of containers. The effect of body height on workload was also not established because the aim was to find one design of a container that would fit a wide range of body heights. Therefore, subjects were chosen to match the distribution of body heights of the refuse collectors in a national study. The assumption was that the results found will also be valid for the general working population of refuse collectors.

A possible source of bias, which might be dependent on the type of container, is the working technique. Although the participants practised with the redesigned container, this training period might have been too short. A longer period of practise with the redesigned container might have resulted in a more efficient working technique. Most likely, this would correspond to an even further reduction of the exerted forces and mechanical loading. For instance, a study on the handling of boxes indicated that strategies used by experienced workers permit better control of the load and a more efficient use of box momentum (Authier *et al.* 1996). In addition, Gagnon *et al.* (1996) found that expert handlers of boxes chose a strategy that was more efficient in terms of mechanical energy expenditure. Chaffin *et al.*

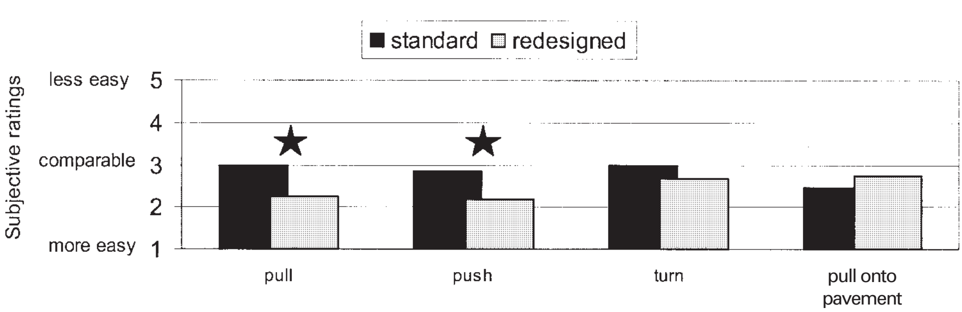

Figure 7. Mean values of the subjective ratings for pulling, pushing and turning the standard and the redesigned containers and for pulling the empty containers onto the pavement (★ statistically significant difference).

(1999) examined the effect of short-term practice on low back stresses during working with a materials handling device. They concluded that, if learning occurs in these tasks, it is at a slow pace.

The way the COM was created in both containers resulted in a small difference in total weight of the containers of up to 3%. However, the effect of the type of container was calculated independent of the effect of weight and of the possible interaction effect of both variables, using GEE analysis. Therefore, this difference did not affect the results. The COM position was created by using blocks of foam and lead. By doing so, the weight of the filling was more or less centred in the container. In reality, refuse is more homogeneously distributed in the container. Therefore, the widening of the redesigned container might result in an increase of the moment of inertia and consequently in an increase in, for instance, the exerted hand forces. The size of this effect on the exerted hand forces was estimated in the following way. The recorded kinematics of the two-wheeled container and the moment of inertia, due to a homogeneous filling, were used to calculate the additional moment around the wheel-axis. Then, the exerted forces at the handles were calculated based on the additional moment around the wheel-axis and the distance from the wheel-axis to the handles. Next, the measured exerted forces and the calculated exerted forces based on the additional moment were compared to estimate the relative contribution of the moment of inertia of a homogeneous container filling. The percentage underestimations of the exerted hand forces for pushing, pulling and turning the standard two-wheeled container were calculated to be 8%, 8% and 12%, and for the redesigned two-wheeled container these were calculated to be 7%, 7% and 9%, respectively. Therefore, despite the widening of the redesigned container, the estimated moment of inertia was smaller for the redesigned two-wheeled container than for the standard two-wheeled container. This was caused by the smaller height of the redesigned container.

Working as a refuse collector of two-wheeled containers is not only considered to be physically demanding in terms of mechanical workload, but also in terms of energetic workload (Frings-Dresen *et al.* 1995b, Poulsen *et al.* 1995, Kuijer *et al.* 2000). In the present study, only the biomechanical effects of handling a two-wheeled container were studied. Therefore, the effect of the design of the container on the energetic workload during the day cannot be established. However, a prediction of the possible benefits can be made on the basis of the results of a study by Van der Beek *et al.* (2000). For pushing and pulling of carts during 15 min, they found that the exerted forces varied between 50 N and 140 N and that the corresponding percentage of the maximum oxygen uptake (%VO_{2max}) varied between 31% and 53%, respectively. A decrease in exerted forces resulted in large reduction of the %VO_{2max}. The average decrease in exerted forces for sustained pulling and pushing of a redesigned container compared to the standard container was about 25% in the present study. Applying the relationship between exerted force and %VO_{2max} from the study by Van der Beek *et al.* (2000) to the present data, a reduction in %VO_{2max} of about 18% during pushing and pulling could be expected. On a working day of about 500 min, the duration pushing and pulling a loaded two-wheeled containers is about 60 min (Kuijer *et al.* 2000). Therefore, an educated guess is that there would be a reduction in energetic workload due to the introduction of a redesigned container, albeit very small.

4.2. *Comparison with other studies*

The exerted forces, moments and compression forces in the present study varied from the results found in three other studies on pulling and pushing of a standard two-wheeled container with a volume of 0.240 m^3 and a weight of about 40 kg (table 1). Differences between the present study and the other studies can be attributed to several causes such as differences in working technique, different positions of COM, differences in surfaces on which the container was transferred or differences in measuring procedures and the ways the sustained and peak values were calculated. For instance, Donders *et al*. (1997) reported a peak force of only 98 N for pushing. This was explained by the fact that the two-wheeled container was already tilted before the pushing measurements started (although, during pulling, the tilting phase was also measured in their study). De Looze *et al*. (1995) used a 2D single equivalent muscle model where net moments at the low back were the result of the activity of one muscle, either one back muscle or one abdominal muscle parallel to the trunk position. The distribution model in the present study estimated the compressive forces on the basis of several muscle groups with different application angles. Despite these different techniques, the peak compression forces for pulling and pushing in the study of De Looze *et al*. (1995) and in the present study were quite comparable, 2051 N vs. 2217 N for pulling and 1818 N vs. 2219 N for pushing, respectively (table 1). Schibye *et al*. (2001) calculated the net moment at the shoulder using a 2D biomechanical model. This might explain why the shoulder moment was relatively low compared to the moments found in the present study.

No study was found in which the contact force at the shoulder joint was quantified for handling two-wheeled containers. Only a few studies have calculated contact forces in the shoulder. Riding a wheelchair against a slope of 2° with a speed of 4 $km \cdot h^{-1}$ resulted in a contact force of about 800 N (Veeger 1999). Bricklaying with stones varying in weight from 4.3 kg and 16.1 kg resulted in contact forces between 500 N and 1500 N (Faessen and Visser 1995). Anglin *et al*. (1997) calculated the

Table 1. A summary of results of studies on pulling and pushing a standard two-wheeled container with a comparable weight (about 40 kg).

Activity	Value	Body region	Type	Standard design (present study) 40 kg	Donders *et al.* (1997) 41 kg	Schibye *et al.* (2001) 40 kg	De Looze *et al.* (1995) 39 kg
Pulling	Exerted force (N)		Peak	126	214	179	
			Sustained	39	58	111	
	Moment (Nm)	Back	Sustained	45		26	
		Shoulder	Sustained	12		1	
	Compression (N)	Back	Peak	2217			2051
			Sustained	1662		938	
Pushing	Exerted force (N)		Peak	138	98	219	
			Sustained	54	42	98	
	Moment (Nm)	Back	Sustained	50		13	
		Shoulder	Sustained	6		2	
	Compression (N)	Back	Peak	2219			1818
			Sustained	2311		542	

contact forces for five activities of daily living in order to derive a suitable load for testing shoulder prostheses. The average contact forces ranged between 1240 N for walking with a cane and 1750 N for lifting a suitcase of 10 kg. In comparison, the contact forces in the present study can be classified as relatively low.

4.3. *Improved design?*

The results showed that, except for the shoulder moment while pulling an empty container onto the pavement, the redesigned container resulted in lower exerted hand forces, lower moments and contact forces at the shoulder, and lower moments at the low back. Remarkably, no effect was found of the type of container on the compression forces at the low back, despite the effect on the moments at the low back. This might be explained by a greater random variation in the estimations of the compression forces due to the stochastic nature of the EMG signal. Also a greater level of co-contraction in the conditions with a relatively low moment at the low back, and/or a change in direction of the moment and its effect on the moment arms of the muscle-slips involved, might be responsible.

The reduction of the hand forces ranged from 13% to more than 50%. For the moments at the low back and the contact forces and moments at the shoulder, the range in percentage reduction was about the same. The correlations between exerted force and moments are low for the low back and high for the shoulder. The correlations between (peak and sustained) exerted force and the (peak and sustained) moment at the low back for pulling, pushing and turning vary between -0.43 and 0.84 (mean 0.39, SD 0.56). For (peak and sustained) shoulder moment, these correlations vary between 0.41 and 0.97 (mean 0.85, SD 0.24). The low correlations for the moment at the low back load and the high correlations for moment at the shoulder load are probably due to the 'extra link' between the low back and the exerted force compared to the shoulder, and to greater variation in trunk position than in shoulder position given an exerted force.

The biomechanical results for pushing and pulling are in line with the subjective ratings of the refuse collectors. Pushing and pulling of the redesigned container was rated as easier than pushing and pulling of the standard container. The subjective ratings for pushing and pulling of the standard container were comparable with pushing and pulling of the normal container in daily practice. No significant differences between the redesigned container and the standard container were found for turning the container and pulling an empty container onto the pavement.

Remarkably, pulling an empty redesigned container onto the pavement resulted in a two times higher peak moment at the shoulder compared to simply pulling the empty redesigned container. The most likely explanation of this result is a less favourable direction of the force with respect to the location of the shoulder joint. This effect might be caused by a complex interaction between handle position, position of the wheel axis in relation to the kerb of the pavement, position of COM in relation to the kerb of the pavement and to the wheel axis. In daily practice, the refuse collectors do not place every two-wheeled container back onto the pavement. Mostly, the containers are placed against the kerb of the pavement. To reduce the mechanical loading of the low back and shoulder, placing containers back on the pavement should be prevented. In that case, it can be concluded that the introduction of the redesigned container could result in a reduction of the low back and shoulder load. However, it should be stressed that a reduction in workload does not necessarily mean a reduction in the risk of low back and shoulder complaints.

In The Netherlands, a refuse collector is allowed to collect a maximum of 514 two-wheeled containers in a time period of 5.5 h (Frings-Dresen *et al.* 1995b). This corresponds to an average of 1.6 two-wheeled containers per minute. The typical pushing and pulling distance of a two-wheeled container is about 8 m. According to the guidelines of Mital *et al.* (1997), the maximum acceptable initial and sustained forces for pushing with two hands are about 200 N and 100 N, respectively. For both types of containers, these values were exceeded in the present study. According to Mital *et al.* (1997), the maximum one handed pull force for males should not exceed 100 N. This limit was also exceeded for both types of containers. NIOSH recommends a maximum compression force on the low back of 3400 N (Waters *et al.* 1993) and this guideline was exceeded for both types of containers. In addition, exposure to pushing and pulling appears to be related to an increased risk for shoulder complaints (Hoozemans *et al.* 2000). Unfortunately, no guidelines are available for maximum acceptable shoulder loads.

In conclusion, both types of container did exceed existing guidelines. Therefore, the question of whether the redesigned container is really better in terms of reducing the risk of musculoskeletal complaints should be raised. In the authors' opinion, the answer to this question should be affirmative. Not only daily exposure but also long-term job exposure determines the risk of musculoskeletal disorders. Every day, year after year, a refuse collector has to handle hundreds of containers. Therefore, given the same amount of refuse and the same number of containers that have to be collected, a relative small decrease in workload due to the introduction of the redesigned two-wheeled container might result in a relevant reduction in the risk of low back and shoulder complaints. Hence, the redesigned container might in the long run be an effective measure to (partly) prevent the onset or worsening of musculoskeletal complaints.

In conclusion, the introduction of the redesigned container for refuse collecting could result in a reduction of the low back and shoulder load, provided that empty containers are placed back on the pavement as little as possible.

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